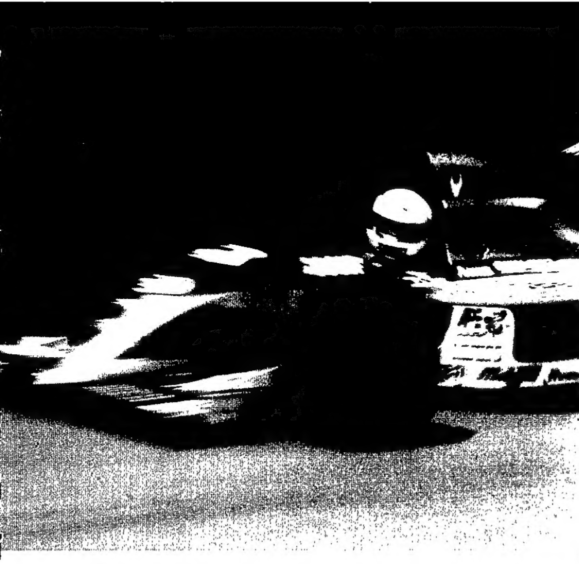

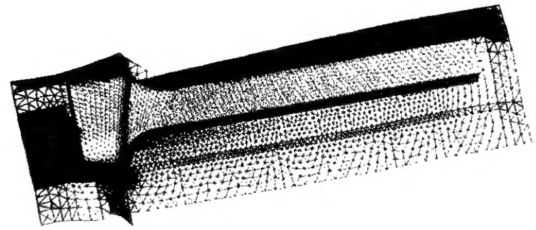

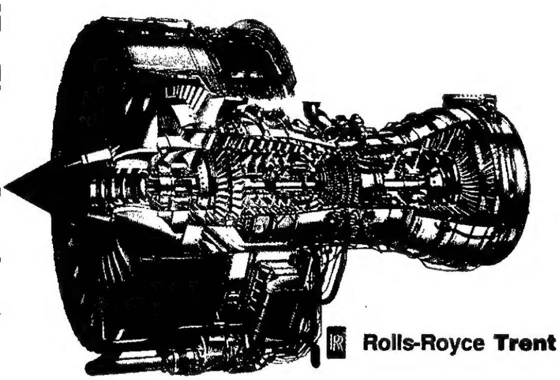

Book of Abstracts

Titanium Alloys at Elevated Temperature: Structural Development and Service Behaviour

11 - 12 September 2000

University of Birmingham
Conference Park,
Birmingham, UK

Conference

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N68171-00-M-5843

BOOK OF ABSTRACTS

Co-ordinated by the High Temperature Materials Performance Committee of the Materials Science and Technology Division of The Institute of Materials and organised by IOM Communications Ltd

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Acknowledgements
The Conference Organising Committee and IOM Communications Ltd would like to express their thanks to the following organisations for their support.

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SESSION ONE: MICROSTRUCTURAL EVOLUTION PART 1

Differential Scanning Calorimetry Study and Computer Modelling of $\beta \Rightarrow \alpha$ Phase Transformation in Ti-6Al-2Sn-4Zr-2Mo Alloy

S. MALINOV, Z. GUO, W. SHA
School of Civil Engineering, The Queen's University of Belfast, Belfast BT7 1NN

Z.X. GUO
Department of Materials, Queen Mary and Westfield College, Mile End Road, London E1 4NS

A. F. WILSON
Timet UK Ltd., PO Box 704, Witton, Birmingham B6 7UR

Abstract

The relationship between heat treatment parameters and microstructure in titanium alloys has so far been mainly studied empirically, using characterisation techniques such as microscopy. Calculation and modelling of the kinetics of phase transformation have not yet been widely used for these alloys, with only limited work on physical modelling of time-temperature-transformation (TTT) diagrams based on Johnson-Mehl-Avrami (JMA) theory.

Differential scanning calorimetry (DSC) has been widely used for study of a variety of phase transformations. There is much work on calculation and modelling of the kinetics of phase transformations for different systems based on the results from DSC study.

In the present work the DSC technique has been used to characterize the $\beta \Rightarrow \alpha$ phase transformation in one of the most commonly used high-temperature titanium alloys, Ti-6Al-2Sn-4Zr-2Mo (Timetal 6-2-4-2). The results are used to trace and model the transformation kinetics in continuous cooling. Based on suitably interpreted DSC results, continuous-cooling transformation (CCT) diagrams are calculated with lines of iso-transformed fraction.

JMA kinetic parameters are derived and the kinetics of transformation are modelled. Good agreement between the calculated and experimental transformed fractions is demonstrated. Utilising the derived kinetics parameters a model is created to monitor the transformation process for an arbitrary cooling path.

The relationship between the cooling rate and the microstructure of the studied alloy are investigated. The influence of the cooling rate on the lattice parameter of the α - phase is shown.

The Use of High Temperature X-Ray Diffractometry to Study Phase Transitions in Ti-6Al-4V

O. Babushkin, R. Pederson and R. Warren

Division of Engineering Materials, Luleå University of Technology, SE 97187 Luleå, Sweden

Abstract submitted to Conference on Titanium Alloys at Elevated Temperature, September 2000 in Birmingham.

ABSTRACT

Phase transitions in Ti-6Al-4V were studied by means of high-temperature X-ray diffraction using a resistance heating furnace in high vacuum and Cu Kα radiation. The alpha and beta phases could be observed conveniently using the (100), (002) and (101) peaks of the alpha structure and the (110) peaks of the beta. Use of a solid state detector system permitted accurate sampling of for example a range of $2\theta = 32\text{-}45^{\circ}$ within 8 minutes. The technique was used successfully to monitor the kinetics of the alpha to beta transition during heating and the beta to alpha transition during cooling and including the transformation kinetics during isothermal holds. Since the examined volume in XRD is confined to a near-surface region, complementary metallographic examination was made to assess the influence of the free surface on transformation.

THE EFFECT OF PROCCESSING PARAMETERS ON SHEAR BANDS IN NON ISOTHERMAL HOT FORGING OF Ti - 6Al - 4V

Morteza Tamizifar (Ph.D) IUST , Hamid Omidvar (MS.C) IUST , Seyyed Mohammad Taghi Salehi (Ph.D) IUST , Zahra Salehpour (BS.C) IUST , Omid Khoshkalam (BS.C) IUST

IUST (Iran University of Science & Technology)

Fax: 0098217454057 E-mail: m_tamizifar@hotmail.com

Abstract:

Ti - 6Al - 4V is prominent as dental and orthopedic (Implant) materials because of their high strength - to - weight ratio , lower elastic modulus , excellent corrosion resistance and apparent biocompatibility.

Since the mechanical characterization of Ti - 6Al - 4V is strongly sensitive to the processing parameters there is relationship between processing variables (i.e. strain rate and temperature) , microstructure and properties under different loading conditions.

Two-phase ($\alpha+\beta$) titanium alloys undergo flow instabilities and they are susceptible to shear bonds or regions of localized deformation crossing many grains during hot forging under non isothermal (dies and work piece at different temperatures) shear bonds can be generated even in materials without flow softening attribute. This occurs if forging parameters wich leads to large amounts of heat transfer between the dies and work piece. This study investigates the occurance of shear bonds in non isothermal , hot forging of Ti - 6Al - 4V in order to evaluate the process parameters wich generally lead to shear bonds in conventional hot forging of metals.

Upset compression tests on cylindrical samples were conducted in a mechanical press and lateral side pressing tests on long , round bars were performed in either the mechanical press or hydroulic press , ranging from axisymmetric to plane strain. In upset samples shear bonds occured at an angle of 45^o to the compression axis and bonds of intense deformation separating chill zones from deforming bulk. Our observation also demonstrate that the fracture can be microvoids nucleated at weak points in the sections of the shear surfaces.

For plane strain deformation, shear bonds were found to initiate along zero extension directions in a manner analogous to the formation and propagation of shear bonds in isothermal, hot forging. Although the shear bond features at hot forging temperature are similar to each other, there is a difference in the hardness and thickness of the shear bonds depends on deformation mode and amount and temperature.

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SESSION TWO: MICROSTRUCTURAL EVOLUTION PART II

Titanium Alloys in High Performance Automotive Engine Applications

The use of titanium alloys at elevated temperatures in high level race engine applications will be reviewed. The paper will indicate how the mechanical, physical and chemical properties of titanium can be either an advantage or disadvantage, depending upon the specific component.

The paper will begin with a review of some of the high temperature components within the engine and their operating conditions. Ease of manufacturing and lead time concerns will also be discussed with a view to their influence on successful application.

Specific component examples will be selected, and analysed in detail to show how manufacturing routes have developed to satisfy rule requirements, performance, durability, and design flexibility issues. Due to the short endurance requirements of modern race engines, temperatures can be far higher than envisaged for aerospace applications. However, low failure rates are still required. The conflicting needs of rapid development and close process control will be discussed with reference to new alloy applications.

The concluding section will indicate possible directions for the future, showing how titanium alloys will replace, and be replaced by, other material systems depending upon the availability of suitable materials with acceptable quality consistency.

Effect of X (Fe, Cr, Co etc.) on the Morphology and Formation of TiC_{1-y} in Ti Alloys with Carbon Additions

Z. Q. Chen Y. G. Li M. H. Loretto
IRC in Materials for High Performance Applications
The University of Birmingham, Edgbaston, B15 2TT, UK
e-mail:zqchen1@yahoo.com tel: (44) 0121 414 3442 fax: (44) 0121 4143441

Abstract

As-cast Ti-15X (Fe, Cr, Co etc.) alloys with 0.2wt% carbon addition have been examined with scanning electron microscopy (SEM) with energy dispersive x-ray analysis (EDX). The principal objective of the study was focused on the effect of X on the morphology and formation of TiC_{1-y} in Ti-15X alloys. It has been found that carbides in Ti-15X (Co, Ni, Ta, Cu, or V) are fine, whereas those in Ti-15X (Fe, Cr, Mn, or Mo)–0.2C are coarse. The volume fraction of carbides in Ti-15Co, Ni, and Cu is much smaller than that in other alloys. The observations are explained in terms of binary Ti-X, X-C, and Ti-C phase diagrams.

Effect of pre-heat-treatment on microstructure and mechanical properties of exposed Ti-25V-15Cr-2Al (wt%) alloys

YG Li, MH Loretto, D Rugg* and W Voice*

IRC in Materials for High Performance Applications, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
*Rolls-Royce Plc, BOX 31, Derby, DE24 8BJ, UK

ABSTRACT

The aim of the present work was to study the effect of pre-heat-treatment on the microstructure and mechanical properties of exposed β titanium alloys of the general composition Ti-25V-15Cr-2Al-0.2C (all compositions are in wt% unless otherwise indicated). It was found that pre-exposure annealing at 600, 700 and 800°C affected the distribution of α that precipitated following subsequent exposure at 500°C. The higher the annealing temperature, the more α precipitated on grain boundaries. Although the room temperature ductility of the alloy decreased and the strength increased slightly with increasing exposure time at 500°, no further drop in ductility was observed after 500h in the sample pre-annealed at 600°C. The significance of the observations is discussed in terms of the effect of pre-exposure annealing and exposure on α precipitation and tensile properties.

Keywords: Titanium alloys, heat-treatment, microstructure, mechanical properties, exposure

Oxidation behavior of a new high temperature titanium alloy – Ti40 burn resistant titanium alloy

YZ Zhao, L Zhou, HL Qu, KY Zhu, H Wu
Northwest Institute for Nonferrous Metal Research
P O Box 51 Xi'an, Shaanxi 711016, P.R. China

Abstract

Ti40 alloy (Ti-25V-15Cr-0.2Si) is a highly stabilized β type burn resistant titanium alloy. Its oxidation mechanism was studied. The weight gain increases greatly with the oxidation temperature, and then decreases when the oxidation temperature is over 1000°C. The oxidized products at 600°C are $Ti0_2$ and V_20_5. If oxidation temperature is greater than 700°C, $Ti0_2$ becomes the main product due to the vaporization of V_20_5. The oxide scale cracks and peels off if the temperature is over 900°C. Si0 has been evidenced in the porous oxides if the temperature is over 800°C, and it vanishes as a result of scale spallation at 1050°C. Small amount of Cr_20_3 has also been detected inside the scales and distributes non-continuously. Reasons of the fast oxidation and its mechanism are analyzed. An oxidation model is suggested.

Keywords: Ti40 alloy, Ti-V-Cr alloy, burn resistant titanium alloy, oxidation mechanism

SESSION THREE: THERMOMECHANICAL PROCESSING

Modelling Structural Development in the Manufacture of Titanium Alloys.

J.W.Brooks[1].

Titanium based alloys are generally manufactured using a route which consists of a number of melting operations followed by a combination of forging and rolling to give final components or semi-finished product suitable for further processing or machining to shape. Extrusion is rarely used for conventional α and α–β alloys due to the need for low process temperatures but it is used in the manufacture of β alloys and intermetallics where the structural requirements allow high metal working temperatures. It is well known that microstructural control in conventional titanium alloys is dependent on the relationship between the working temperature and the allotropic phase change between the α phase (hcp) and the β phase (bcc) that occurs, at the β transus, in the range 800-1050 °C. Grain growth in the high temperature β phase field is rapid and consequently ingot structures and material worked above the β transus are characterised by coarse grains. The aim of titanium alloy processing is, therefore, to control the solidification microstructure during melting to minimise segregation and coarse macrostructural features followed by hot working schedules designed to give structural refinement using β phase recrystallisation, while minimising subsequent β grain growth, followed by further deformation in the α–β phase field.

Microstructural control can, therefore, be divided into three main areas:-

(i) Solidification structures obtained in melting.
(ii) β worked and recrystallised structures and
(iii) Sub-transus deformation mechanisms.

This paper will examine the various manufacturing processes and the associated modes of structural development and will review the modelling activity which has been attempted. The latter fall into three main areas which broadly correlate with the different structural regimes. Eg.

(a) Solidification models of vacuum arc or plasma remelting which range from relatively simple thermal field predictions to more complex analyses including fluid flow. The primary aims are to predict ingot chemistry with less emphasis on structure.
(b) Ingot forging modelling and the prediction of primary worked structures is only just becoming feasible from a computational viewpoint and is currently the subject of a number of development projects.
(c) Modelling the α–β spherodisation process in the secondary working operations. There has been considerable effort spent in attempting to understand the metallurgical processes involved in this area but there has been little real success in implementing this into constitutive relationships suitable for the simulation of microstructural development due to the complex nature of the deformation mechanisms in the two phase region.

[1] Room 2008, Bldg. A7, DERA, Farnborough, Hampshire. GU14 0LX

The application of a novel technique to examine thermomechanical processing of titanium alloys

M Jackson
Imperial College of Science, Technology and Medicine, UK

Abstract

A novel specimen design and testing strategy has been exploited to determine the effect of thermomechanical processing on the microstructural development of titanium alloys. A double truncated cone test geometry is isothermally deformed at near β transus temperatures, to obtain microstructrual information for a range of strains within a single specimen. A finite element modelling (FEM) package, is then employed to produce strain profiles, which readily correspond to the equivalent microstructural profiles of the test specimens. A parametric study of the effects of process (e.g. friction) and material (e.g. strain rate sensitivity) parameters on the strain distributions obtained during the test are also investigated. The effectiveness of this testing strategy is illustrated with a qualitative description of the microstructural evolution with strain, for various strain rates, at sub β transus forging temperatures for a number of titanium alloys.

Microstructural characterisation and modelling of aTi-6Al-4V alloy during thermomechanical processing in the β phase field

R. Ding, Z.X. Guo

Department of Materials, Queen Mary & Westfield College,
University of London, London E1 4NS;

W. Sha

School of Civil Engineering, The Queen's University of Belfast,
Belfast BT7 1NN, Northern Ireland;

A. Wilson

Timet UK Ltd, P.O. Box 704, Witton, Birmingham, B6 7UR, UK.

Abstract

The microstructural evolution of a Ti-6Al-4V alloy during thermomechanical processing in the β phase field was investigated both experimentally and via modelling. The influence of strain rate and temperature on the microstructural evolution was considered. The experimental results show that dynamic and/or metadynamic recrystallization occurred when processed in the β phase field. The simulation results show that both the percentage of DRX and the mean size of the DRXed grains increase with increasing temperature and decreasing strain rate. The predicated mean dislocation density fluctuates at lower strain rates or high temperatures, and gradually stabilises with increasing strain rate or decreasing temperatures.

Keywords: Ti-6Al-4V alloy, thermomechanical processing; microstructure; dynamic recrystallization; modeling

Elevated temperature fatigue crack growth and time dependent behaviour in Ti6246

J.P. Jones, M.R. Bache, W.J. Evans, S. Williams*
IRC in Materials for High Performance Applications
University of Wales, Swansea, SA2 8PP, United Kingdom.

*Rolls Royce plc
P.O. Box 31, Derby, DE2 8EJ, United Kingdom

Abstract

Fatigue crack propagation behaviour of the titanium alloy Ti 6246 has been investigated at room and elevated temperatures. Using stress intensity range, ΔK, as a correlating parameter, fatigue crack growth rates were found to be insensitive to variations in positive mean stress and waveform at 20°C. This is attributed, in part, to the refined microstructure. However, a fine grain size is often associated with inferior high temperature creep behaviour and can accentuate the diffusion of aggressive species along grain boundaries. As a result, at the higher temperatures measured growth rates generally increased and became dependent on R ratio and periods of dwell loading at peak stress. Additional testing under a hard vacuum condition have been implemented to characterise creep-environmental fatigue interactions.

SESSION FOUR: ADVANCED FABRICATION I

Surface and substrate stability of titanium alloys used in aerospace applications

CD Jones
Discs & Lifting Group
Technology
Rolls-Royce plc
P O Box 31, Derby DE24 8BJ, UK

ABSTRACT

Long term stability is important for components that operate at high stress throughout their service life. For aero-engine parts the life expectation can be considerable; a 15,000 flight cyclic life is not uncommon. In this paper material structure and property issues relating to bulk and surface stability will be overviewed for a range of current Titanium alloys

Weld Repair of Titanium Alloys

L.S. Smith and M.F. Gittos
TWI, Granta Park, Great Abington, Cambridge, CB1 6AL, UK

Whilst titanium alloys offer a viable lightweight and/or corrosion resistant solution for many applications, the perceived sensitivity of welds to certain defects places often extreme requirements on quality. Thus, titanium alloy joints are often judged more harshly than those in other engineering materials, leading to greater rejection rates and significantly increased costs in what is probably already a very expensive component. Thus, it is crucial that any fabrication defects be repaired successfully, even though any repair welds will be just as susceptible to defects as the original weldment. The high cost of titanium components has also led to the development of intricate repair welding procedures for extending the life of items that have exceeded their original service life, mainly as a consequence of wear. In such instances, weld defects can again prove extremely problematic. The current paper reviews the formation and avoidance of the prevalent defects leading to the rejection of titanium welds. The significance of these defects is highlighted and the basis for weld rejection criteria is discussed.

Welding of Ti-10V-2Fe-3Al, a Comparison of Techniques

I.C.Wallis, A.Wisbey
Mechanical Sciences Sector, DERA, Farnborough, Hants. GU14 0LX. UK.
Tel. 44 (1252) 393808, Fax 44 (1252) 397303
E mail – AWisbey@dera.gov.uk

Abstract

Mass reductions in aircraft structures via the introduction of high strength titanium alloys are attractive because of the enhanced fuel economy or payload that can be achieved. However, such mass reductions must be obtained for a minimum cost penalty. This economic consideration, together with the high cost of titanium alloys and the drive to reduce the part count suggests that fabrication will be essential in the manufacture of structures. Joining of high strength titanium alloys by conventional fusion welding techniques can be problematic, with microstructural inhomogeneities and chemical segregation occurring. Post weld heat treatment may improve the weld properties but it is difficult or impossible to balance the mechanical characteristics of the weld and bulk material. As a result of these known problems a range of welding techniques have been applied to the near β titanium alloy, Ti-10V-2Fe-3Al in order to assess their relative performance. TIG and EB fusion welding have been used and compared with the solid state joining processes of friction welding and diffusion bonding. Post weld heat treatment has been performed and the microstructural development in both the fusion/bonding zone and heat affected zone has been observed. The relationship between the microstructural features of the joints and the tensile properties was assessed. It is clear from this study that the solid state joining processes offer the best balance of strength and toughness, with the friction welding in particular offering high toughness.

SESSION FIVE: ADVANCED FABRICATION II

Surface Engineering of Titanium Alloys

J. R. Nicholls
Cranfield University, Cranfield, Bedford, MK43 0AL

ABSTRACT

Titanium alloys, when exposed in air at elevated temperatures, (>500°C), readily absorb oxygen leading to alpha-case formation which has been shown to severely limit the high-temperature capability of alloys in terms of mechanical properties. In order to extend the temperature capability of in particular the high strength creep resistant alloys, e.g. IMI834, therefore, coating systems are required which limit the ingress of oxygen.

This paper will review the traditional methods used to coat titanium alloys and discuss the performance of such coating systems with high temperature exposure, particularly the formation of embrittled surface layers.

A novel coating process will be presented whereby a 'thin' (circa 1 to 3μm) $PtAl_2$ intermetallic diffusion barrier layer can be produced and is used to limit the ingress of oxygen which prevents the formation of alpha-case. The stability of the system has been demonstrated, using vacuum heat treatment trials, for temperatures up to 900°C. The inherent oxidation resistance of the $PtAl_2$ layer is found to be totally protective following 100 hours exposure at 700°C with a six fold improvement over uncoated IMI834 after 100 hours at 800°C. The application of a NiCr overlay, which forms a 'p-type' Cr_2O_3 oxide, gives further improvements by preventing oxygen ingress. The $PtAl_2$ layer in this case also acts as a diffusion barrier for nickel and chromium.

The microstructure and superplastic properties of mechanically milled Ti-6Al-4V + 0.5% B.

TMT Godfrey[1], A Wisbey[1], PS Goodwin[1], CM Ward-Close[1], A Brown[2], C Hammond[2]

[1]Structural Materials Centre, DERA Farnborough, Hampshire GU14 OLX
[2]Dept. of Materials, The University of Leeds, Leeds LS2 9JT

ABSTRACT

Superplastic forming of conventional titanium alloy sheet is limited commercially by the relatively long cycle times imposed by the high temperatures and slow strain rates required for forming. In order to minimise cycle times material with a fine grain size is required to enable increases in the forming rate and/or reductions in the deformation temperature. This study details an investigation of the production of fine grained Ti6Al-4V + 0.5%B. Ti-6Al-4V + 0.5% B powder with nanocrystalline grains was produced by mechanical milling (MM). The material was consolidated by hot isostatic pressing at a range of temperatures during which TiB was formed by an in situ reaction between the titanium and the boron. The aim of the TiB was to pin the fine grain size of the titanium produced by mechanical milling. The consolidated material was hot tensile tested at a range of temperatures and strain rates. A superplastic elongation of 490% was achieved when testing at 900°C at a strain rate of 6×10^{-2} s^{-1} compared with 220% for conventional Ti-6Al-4V sheet. Cavitation was observed along the gauge length of the boron containing samples however, this was thought to relate to argon entrapment and was seen in mechanically milled Ti-6Al-4V (without boron) and not to the TiB needles

SESSION SIX: STRUCTURAL CONTROL OF TI INTERMETALLICS

PRACTICAL ADVICE ON THE USE OF Ti-45-2-2-XD™ GAMMA TITANIUM ALUMINIDE

Dr Wayne Voice

Rolls-Royce plc.
Materials: Compressor Aerofoils
(Elt-38), P.O. Box 31
Derby, DE24 8BJ, UK

Abstract

Gamma titanium aluminide is likely to be used in commercial aero-engines in the near future. Alloys with a reasonable balance of mechanical properties are available and waiting for the opportunity to displace existing materials to give benefits in weight, fire resistance and stiffness. Rolls-Royce has the Ti-45-2-2-XD™ alloy in a state of readiness for compressor components and has investigated the practical aspects of introducing this material. The effects of casting, HIP'ing and heat treatment are described in relation to mechanical properties of the finished article. Also discussed is how well the material withstands exposure to air at aero-engine operating temperatures.

Hot plastic-flow and workability of γ-TiAl based alloys

Y. Y. Cui [a], R. Yang [a] and Z. X. Guo [b]

[a] Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110015, China

[b] Department of Materials, Queen Mary and Westfield College, Mile End Road, London E1 4NS, UK

ABSTRACT

The hot workability of Ti-47Al-2Cr, Ti-46.5Al-4Cr, Ti-46.5Al-2Cr-5Nb and Ti-46.5Al-5Nb (at.%) was assessed in the wrought condition through a series of tension tests conducted over a practical range of forging strain rates and temperatures. Tensile flow curves for the four γ-TiAl based alloys exhibited sharp peaks at low strain levels followed by pronounced necking and flow localization at high strain levels; notably, a second and even a third peak can be observed on the tensile flow curves at the condition of low temperatures and high strain rates in all alloys except Ti-46.5Al-2Cr-5Nb. A phenomenological analysis of the strain rate and temperature dependence of the peak stress data yielded average values of the strain rate sensitivity of 0.225, 0.213, 0.216 and 0.208, and apparent activation energy of 419, 539, 504 and 507 kJ/mol for Ti-47Al-2Cr, Ti-46.5Al-4Cr, Ti-46.5Al-2Cr-5Nb and Ti-46.5Al-5Nb, respectively. All the peak stresses conform to the power-law formulation $\sigma_p = kZ^m$, the coefficient k and exponent m varying with the alloys. Ductility in terms of reduction in area of all tensile samples was strongly dependent on the strain rate - temperature condition, and a critical value of the $\sigma_p\sqrt{d}$ for brittle fracture was determined to be ≈ 1.5 MPa$\sqrt{\mathrm{m}}$.

Effect of grain refinement on continuous cooling phase transformation n some TiAl-based alloys

D Hu

Interdisciplinary Research Centre of Materials for High Performance Applications
The University of Birmingham, Edgbaston, Birmingham B15 2TT

Abstract

Grain refinement is an effective approach to obtain balanced properties of TiAl-based alloys. It has been found that the same cooling rate from the single alpha phase field can result in different microstructures in grain refined and non-grain refined alloys with similar compositions. Our studies show that grain refinement affects the continuous cooling phase transformation behaviour. In grain refined TiAl-based alloys the critical cooling rates required for certain microstructures are increased and the lamellar formation windows are moved towards higher temperatures compared with those in non-grain refined alloys.

Deterioration of Mechanical Properties Caused by Omega Phase in Major Alloyed TiAl-based Alloys

Z.W. Huang*, W. Voice** and P. Bowen*

* Interdisciplinary Research Centre in Materials for High Performance Applications/School of Metallurgy and Materials, The University of Birmingham, Edgbaston, Birmingham B15 2TT, UK.
** Rolls-Royce plc, PO Box 31, Derby DE24 8BJ, U.K.

Abstract

The addition of 1.0 at % boron has successfully reduced the lamellar colony size to 50 μm for alloy Ti-44Al-8Nb-1B and to 80 μm for alloy Ti-44Al-4Nb-0.2Si-1B. However, the latter is found to have a considerable amount of omega phase precipitated from retained β under as-HIPped conditions. In order to understand the effects of omega phase, mechanical performance in tensile, fatigue and fatigue crack growth resistance tests has been assessed for these two alloys, and has been combined with detailed TEM examination. Omega particles existing as a network around retained beta cells are deduced to be favoured sites for microcrack initiation under both monotonic and cyclic loading conditions. On the other hand, no influence on the fatigue crack growth resistance has been found as a result of the presence of omega phase. The relationships between microstructure and mechanical properties for the two alloys are discussed.

Prediction of Omega Phase Formation in Ti-Based Intermetallic Alloys

G Shao and P Tsakiropoulos

University of Surrey, School of Mechanical and Materials Engineering, Guildford, Surrey GU2 5XH, UK

The omega phase is detrimental to the mechanical properties of Ti-based alloys, when a precursor high temperature bcc type phase (beta phase: A2 or B2 structure) is involved. This is particularly important for the design of the new-generation TiAl-based alloys, where beta-stabilising transition metal elements have been considered for improving the low temperature ductility. The interaction between Al and transition metals in these alloys could lead to the stabilisation of the beta phase via chemical ordering and the formation of ordered omega structures in the ordered parent beta phase. In this paper general rules are proposed for the prediction of omega phase formation in Ti-based intermetallic alloys. The omega phase stability with reference to the parent beta phase will also be discussed, on the basis of new experimental and theoretical evidence.

Thermal processing of an orthorhombic (Ti_2AlNb) alloy

PM Sarosi, A Partridge* & IP Jones
University of Birmingham, Edgbaston, Birmingham B15 2TT
*DERA, Building A7, Farnborough, UK

Abstract

An orthorhombic (Ti_2AlNb) alloy of composition Ti-23Al-21Nb (atomic%) plus alloying additions has been investigated, using optical microscopy, scanning electron microscopy (SEM) and transmission electron microscopy to determine the β-transus, upper O (orthorhombic) solvus and lower α_2 solvus. In addition, time temperature transformations and continuous cooling transformations have also been investigated. The β-transus, upper O solvus and lower α_2 solvus are 1100°C +/-10°C, 935°C +/-10°C and 905°C +/-10°C respectively. The time temperature transformation study indicates a maximum hardness due to precipitation hardening at 850°C for 1 hour. Cooling at 5°C per minute, above the β-transus inhibits the precipitation of α_2 compared with cooling at 5°C from below the β-transus. This indicates that nucleation of α_2 is an important factor governing of α_2 precipitation.

POSTERS

Fatigue properties of difussion layers produced on titanium alloys by plasma combined methods of surface treatments

JR Sobiecki, T Wierzchoń, T Karpiński, J Rudnicki
Faculty of Materials Science and Engineering
Warsaw University of Technology
02-507 Warszawa ul. Woloska 141, Poland

Abstract

With increasing progress in engineering a growing need has been felt for materials that show improved surface properties, such as an increased resistance to wear and to corrosion. These requirements can be satisfied by producing surface layers of specified microstructure and composition. New methods for producing such layers on titanium alloys are plasma nitriding, oxynitriding and carbonitriding using the glow discharge conditions.

The paper contains results and discussion of the rotating bending fatigue tests which have been carried out using materials with different microstructures $TiN + Ti_2N + \alpha Ti(N)$ layers produced on titanium alloys in plasma nitriding processes and $Ti(CN) + Ti_2N + \alpha Ti(N)$ obtained in carbonitriding process using the glow discharge conditions.

The results of the paper unanimously confirm the positive effect of the plasma treatments of titanium alloys.

The metallographic, phase composition investigations and the wear and corrosion resistance of these layers will also be compared.

Influence of strain parameters on deformation resistance of Ti-6Al-4V titanium alloy at 1173-1273K

K. Kubiak, W. Ziaja, M. Motyka, J. Sieniawski
Rzeszów University of Technology, POLAND

Abstract

In the paper results of the studies on two-phase martensitic titanium alloy Ti-6Al-4V have been presented. The alloy was deformed in the torsion and static tensile tests at the temperature of 1173, 1223 and 1273K at the strain rate ranging from $\varepsilon;^{\bullet} = 1.0\cdot10^{-4}s^{-1}$ to $\varepsilon;^{\bullet} = 4.0\cdot10^{-4}s^{-1}$. Plastic flow stress changes were estimated, along with change in primary β-phase grain diameter and α-phase volume fraction at the temperature of the test.

Mechanical properties of closed-die forgings of Ti-6Al-2Mo-2Cr titanium alloy as a function of heat treatment parameters.

K. Kubiak, M. Motyka, W. Ziaja
Rzeszów University of Technology, POLAND

Abstract

In the paper results of the studies on two-phase martensitic titanium alloy Ti-6Al-2Mo-2Cr have been presented. Phase composition and microstructure of closed-die forgings were examined for various forging and heat treatment conditions. Tensile and fatigue tests were carried out. Solution treatment and ageing parameters providing the best fatigue strength of the alloy were determined.

Effect of Oxygen on Mechanical Properties of Ti-64 and Ti-6242

A.P. Woodfield

GE Aircraft Engines
1 Neumann Way, M-89
Cincinnati, OH 45215

The impact of elevated oxygen levels, up to 0.5 weight percent, on tensile, low cycle fatigue (LCF) and dwell LCF properties of Ti-64 and Ti-6242 was determined from room temperature through 500F. The materials to be tested were produced as ~120lb triple vacuum arc re-melt ingots, converted to 4" diameter, followed by alpha/beta extrusion and heat treatment. The tensile data show that the strength of Ti-6242 was increased significantly with the elevated oxygen content, while the low temperature ductility of Ti-6242 was reduced substantially. In contrast, the tensile properties of Ti-64 were relatively unaffected by the addition of 0.5 weight percent oxygen. Both LCF and dwell LCF properties increased when tensile strength was increased. The microstructure and texture for all the tested materials were found to be similar, suggesting another explanation for the difference in mechanical behavior of Ti-6242 and Ti-64. The increased strength and reduced low temperature ductility observed in Ti-6242 with 0.5 weight percent oxygen was presumed to be related to Ti_3Al formation in the more highly alpha stabilized Ti-6242 alloy.

THEORETICAL ANALYSIS OF THE COMPOSITION OF α_1 PLATES ISOTHERMALLY FORMED IN TITANIUM BINARY ALLOYS

S.A. Mujahid

PINSTECH, P. O. Nilore, Islamabad, Pakistan

ABSTRACT

The solute distribution near the α plates which grow isothermally from β solid solution in binary alloys of titanium has been investigated theoretically with a view to clarifying whether the plates grow without diffusion or whether the partitioning of solute occurs after transformation. To check whether the latter mechanism is plausible, calculations have been conducted of the diffusion profile of solute and of the time required for the plate to achieve its equilibrium composition. The calculations use a mathematical model based on a finite difference technique. The results have been compared with published experimental data.

RESIDUAL STRESSES, TEXTURE AND MICROSTRUCTURE IN ELECTRON BEAM WELDS OF IMI 834

J-R. CHO, K.T. CONLON*, S.M. ROBERTS AND R.C. REED

University of Cambridge / Rolls-Royce University Technology Centre,
Department of Materials Science and Metallurgy,
Pembroke Street,
Cambridge CB2 3QZ, UK

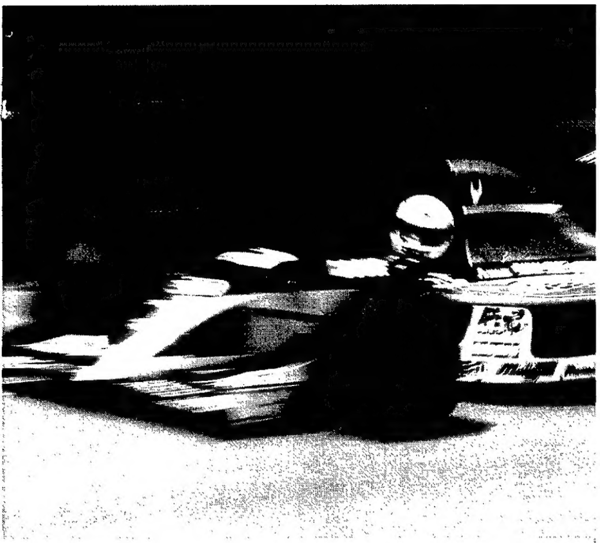
*National Research Council of Canada, Chalk River Laboratories,
Chalk River, Ontario, KOJ, 1JD, Canada.

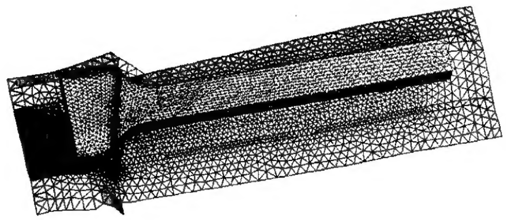
Abstract

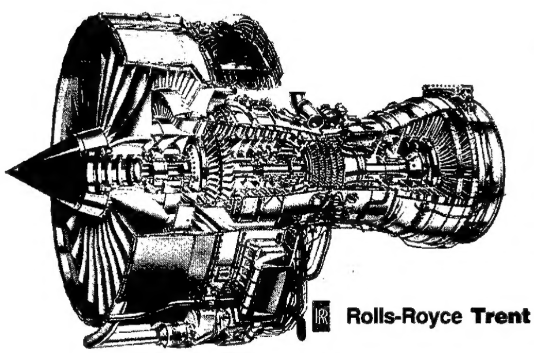
IMI 834 is a near-α alloy which is now used widely for the fabrication of the compressor assemblies of modern gas turbine engines. For such applications, electron beam welding is frequently employed to join together the compressor discs. The major advantages of electron beam welding are (i) weld profiles of high penetration can be obtained so that thick sections can be joined, (ii) the likelihood of weld contamination by oxide inclusions is small, since processing is carried out in vacuum and (iii) the process has proved amenable to automation, so that autogenous welds of extremely high quality can be produced in manufacturing environments.

Nonetheless, the application of the electron beam causes a thermal-mechanical response in the workpiece and thus a complicated pattern of residual stresses is set up. It is of interest to quantify the residual stresses which arise, as these need to be accounted for when estimating component strength and fatigue life. In this paper, strain measurements on electron beam welds of IMI-834 are reported; these have been made using neutron diffractometry. Three-dimensional scans have been performed, *i.e.* in the longitudinal, transverse and normal directions, with the aid of $(10\bar{1}3)$ reflection at a 2θ angle of 85.4°. In order to estimate the residual stresses from the residual strains, additional in-situ loading experiments have been carried out on tensile testpieces to quantify the positions of the Bragg reflections as a function of increasing applied load. These provide the diffraction elastic constants required for the accurate conversion of the measured strains to stresses. The plane specific constants (Young's modulus and Poisson's ratio) for the $(10\bar{1}3)$ reflection have been determined to be 128 GPa and 0.32, respectively. The residual stresses are then calculated from linear elasticity theory. In the as-welded state, the stresses are large – approximately 550 MPa in the vicinity of the weld and largest in the longitudinal (welding) direction.

Further experiments have been carried out in order to characterise the texture which develops in the weld, which is considerable. These data have been compared with observations made using traditional metallographical techniques.







Final Programme

Titanium Alloys at Elevated Temperature: Structural Development and Service Behaviour

11 - 12 September 2000

University of Birmingham
Conference Park,
Birmingham, UK

Organised by:

IOM Communications

Conference

Final Programme

Monday 11 September 2000

09.00 **Registration and Coffee**

10.30 **Welcome and Introduction by the Conference Chairman**
M Winstone (DERA, UK)

SESSION ONE: MICROSTRUCTURAL EVOLUTION PART I
Session Chair: D Rugg (Rolls-Royce plc, UK)

10.45 **Keynote: Titanium market development: the implications for research and development**
R Thomas (Timet UK Ltd, UK)

11.15 **Differential scanning calorimetry study and computer modelling of $\beta \Rightarrow \alpha$ phase transformation in Ti-6Al-2Sn-4Zr-2Mo alloy**
S Malinov, Z Guo & W Sha (The Queen's University of Belfast, UK) ZX Guo (Queen Mary and Westfield College, UK) & AF Wilson (Timet UK Ltd, UK)

11.35 **The use of high temperature X-ray diffractometry to study phase transitions in Ti-6Al-4V**
R Pederson, O Babushkin & R Warren (Lulea University of Technology, Sweden)
F Skystedt (Volvo Aero Corporation, Sweden)

11.55 **The effect of processing parameters on shear bands in non isothermal hot forging of Ti-6Al-4V**
M Tamizifar, H Omidvar, SMT Salehi, Z Salehpour & O Khoshkalam (Iran University of Science and Technology, Iran)

12.15 **Discussion**

12.30 **Lunch**

SESSION TWO: MICROSTRUCTURAL EVOLUTION PART II
Session Chair: M Winstone (DERA, UK)

13.30 **Titanium alloys in high performance automotive engine applications**
MT Cope (Ilmor Engineering Ltd, UK)

14.00 **Effect of X (Fe, Cr, Co etc.) on the morphology and formation of TiC_{1-y} in Ti alloys with carbon additions**
ZQ Chen, YG Li & MH Loretto (IRC in Materials, University of Birmingham, UK)

14.20 **Effect of pre-heat-treatment on microstructure and mechanical properties of exposed Ti-25V-15Cr-2Al (wt %) alloys**
YG Li & MH Loretto (IRC in Materials, University of Birmingham, UK)
D Rugg & W Voice (Rolls-Royce plc, UK)

Tuesday 12 September 2000

SESSION FOUR: ADVANCED FABRICATION I
Session Chair: J Nicholls (Cranfield University, UK)

09.00 **Surface and susbstrate stability of titanium alloys used in aerospace applications**
CD Jones (Rolls-Royce plc, UK)

09.30 **Weld repair of titanium alloys**
LS Smith & MF Gittos (TWI, UK)

09.50 **Welding of Ti-10V-2Fe-3Al, a comparison of techniques**
IC Wallis & A Wisbey (DERA, UK)

10.10 **Residual stresses, texture and microstructure in electron beam welds of IMI 834**
J-R Cho, SM Roberts & RC Reed (University of Cambridge/Rolls-Royce University Technology Centre, UK) KT Colon (National Research Council of Canada, Canada)

10.30 **Discussion**

10.50 **Coffee**

SESSION FIVE: ADVANCED FABRICATION PART II
Session Chair: I Jones (IRC in Materials, University of Birmingham, UK)

11.10 **Keynote: Surface engineering of titanium alloys**
JR Nicholls (Cranfield University, UK)

11.30 **The microstructure and superplastic properties of mechanically milled Ti-6Al-4V + 0.5% B**
TMT Godfrey, A Wisbey, PS Goodwin & CM Ward-Close (DERA, UK) A Brown, R Brydson & C Hammond (The University of Leeds, UK)

11.50 **Discussion**

12.10 **Lunch**

SESSION SIX: STRUCTURAL CONTROL OF TI INTERMETALLICS
Session Chair: A Partridge (DERA, UK)

13.30 **Practical advice on the use of Ti-45-2-2-XD™ gamma titanium aluminide**
WE Voice (Rolls-Royce plc, UK)

14.00 **Hot plastic-flow and workability of γ- TiAl based alloys**
YY Cui & R Yang (Institute of Metal Research, China) & ZX Guo (Queen Mary and Westfield College, UK)

AD NUMBER	DATE	DTIC ACCESSION NOTICE

1. REPORT IDENTIFYING INFORMATION

A. ORIGINATING AGENCY

I.B.M UK.

B. REPORT TITLE AND/OR NUMBER

Structural Development & Service Behaviour

C. MONITOR REPORT NUMBER

2967-AN-92

D. PREPARED UNDER CONTRACT NUMBER

~~FFB~~ N68171-00-M-5243

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